

## A DESCRIPTION OF THE NEW INSULATION TEST FACILITIES AT SUNY/AB\*

T. Bilodeau, M. Treanor, A. Hammoud, G. FitzPatrick and J. R. Laghari  
Department of Electrical and Computer Engineering  
State University of New York at Buffalo  
312 Bonner Hall  
Buffalo, New York 14260

### Abstract

The new facilities at the SUNY/AB High Field Materials Research Laboratory and Dielectric Diagnostics Laboratory include pulse, impulse, and ac generation systems, as well as apparatus for dielectric measurements, electrical and thermal prestressing, and liquid impregnation of dielectric films. These facilities are described here, and the results of some representative tests are presented in order to demonstrate the application of the apparatus to insulation research.

### I. Introduction

Insulation testing facilities at the SUNY/AB High Fields Materials Research Laboratory (HFMR) and the Dielectric Diagnostic Laboratory (DDL) have been set up to study the effects of electrical and thermal prestressing upon the physical properties of the new composite dielectric systems proposed for use in high-voltage energy storage and transfer devices. A typical system consists of an insulating film (such as polypropylene) impregnated in a liquid dielectric (such as an aromatic hydrocarbon oil). In these facilities the major electrical test apparatus comprise a capacitance bridge, an ac partial discharge analysis system, an impulse generator and a high-voltage pulser for repetitive breakdown voltage measurements. To complement the electrical measurements, there are mechanical test apparatus which can measure tensile strength, Young's modulus, complex modulus and mechanical loss ( $\tan \delta$ ). Also, there are dielectric film impregnation facilities and equipment to implement simultaneous electrical-and-thermal aging studies. The apparatus described in this paper offers a unique variety of ways to characterize an insulation system. This characterization can ultimately lead to the development of mathematical models which permit both quantitative description and prediction of the breakdown phenomenon, therefore leading to an efficient and reliable design of high voltage systems.

The purpose of this paper is to describe the function and use of the major insulation research facilities at the HFMR/DDI. In addition, the research capabilities of the HFMR/DDI are demonstrated by presenting some of the data obtained in a representative investigation of polypropylene films impregnated in a commercially available aromatic hydrocarbon liquid. The results are not discussed or analyzed in detail because the main intent of this paper is to demonstrate the insulation research capabilities of the HFMR/DDI.

### II. Description of Test Facilities

The design and operation of the equipment used for the impregnation of dielectric films, electrical and thermal prestressing, electrical tests, and mechanical tests are described in the following subsections.

\* partially supported by W. J. Schafer Associates, Inc., AFOSR, Exxon, Hughes, Photochemical Research Associates, The U.S. Army Electronics Technology and Devices Laboratory, Sandia National Laboratory, Carborundum, Inc., Los Alamos National Laboratory, EPRI, Defense Nuclear Agency and the State University of New York.

### II.1 Impregnation

The impregnation system consists primarily of a NAPCO vacuum oven, Model 5831, which has a built-in thermometer, a regulating thermostat as well as a safety thermostat. It also has a 30-in Hg vacuum gauge and two openings, one for the vacuum pump to evacuate the oven, and the other for the impregnant liquid to enter the oven. In order to maintain the vacuum at the proper level, a DUO SEAL vacuum pump, Model 1397, which has four times the capacity of the variable leak rate and load requirements, is used in conjunction with the oven. A block diagram of a typical impregnation cycle is shown in Figure 1.

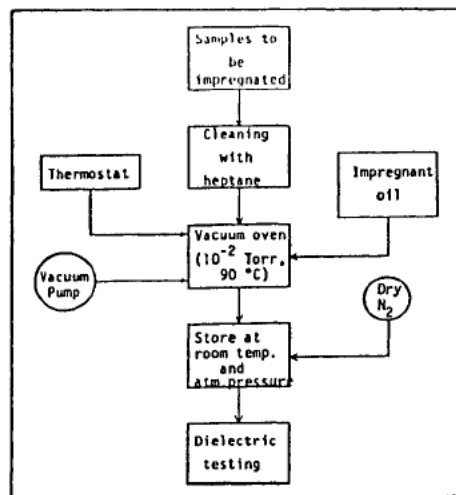


Figure 1. Block diagram of the impregnation cycle.

### II.2 Aging Facility

The aging facility has the capability of electrically and thermally prestressing the impregnated samples prior to electrical and mechanical testing. The desired high voltage input into the oven (described below) which can reach up to 15 kV can be obtained from either one of the two available power supply units: a Hipotronics 100 kV, 20 kVA, ac Dielectric Test Set Model 7100-20; and a Hipotronics 30 kV, positive-polarity corona-free dc power supply Model 230-10 CT/4498-1. The high voltage to the inside of the oven is fed by a flexible silicone rubber insulated high voltage cable designed especially to be corona-free at voltages below 15 kV. A Fisher ISO Temp oven Model 338F, which has an internal blower to insure uniform temperature distribution, is used for thermal aging. The oven has four sealed openings to permit access to the thermometer, the high voltage cables, the nitrogen inlet and the exhaust pipe. The oven, which has a volume of about 10 cubic feet, can be used to age several hundred samples of dielectric films in different impregnants simultaneously.

### II.3 Dielectric Characteristics

The sample thickness, dielectric constant, and the electrical loss tangent at frequencies from 50 Hz to 10 KHz can be measured using a General Radio 1620-A Capacitance Bridge. The sample cell has an arrangement of four concentric brass electrodes as shown to scale in Figure 2 [1].

Using the 4-ring arrangement, the thickness of the specimen placed between the inner two electrodes can be calculated electrically [1]. Also, using the bridge described above, one can calculate the

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>JUN 1985</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>A Description Of The New Insulation Test Facilities At Suny/AB</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Department of Electrical and Computer Engineering State University of New York at Buffalo 312 Bonner Hall Buffalo, New York 14260</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.</b>					
14. ABSTRACT <b>The new facilities at the SUNY/AB High Field Materials Research Laboratory and Dielectric Diagnostics Laboratory include pulse, impulse, and ac generation systems, as well as apparatus for dielectric measurements, electrical and thermal prestressing, and liquid impregnation of dielectric films. These facilities are described here, and the results of some representative tests are presented in order to demonstrate the application of the apparatus to insulation research.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>SAR</b>	18. NUMBER OF PAGES <b>4</b>	19a. NAME OF RESPONSIBLE PERSON
a REPORT <b>unclassified</b>	b ABSTRACT <b>unclassified</b>	c THIS PAGE <b>unclassified</b>			

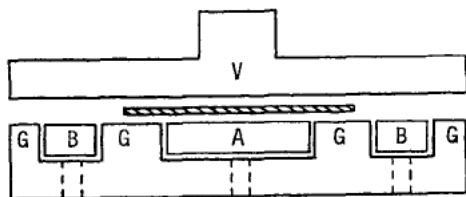


Figure 2. Concentric ring electrode assembly for dielectric measurements (V:upper electrode; A:center electrode; B:ring electrode; G:guard electrode)

dielectric constant and dielectric loss at various frequencies.

#### II.4 AC Partial Discharge Analysis System (PDA) System

The PDA (Biddle Instrument Co., Model 4) is used to determine the ac partial discharge (PD) characteristics and breakdown voltage for an insulation test specimen. The PD characteristics that are usually measured with the PDA are the PD inception and extinction voltages (i.e., PDIV and PDEV). The PDA is comprised of four major components; namely the high voltage (HV) ac supply, power separation filter (PSF), PD amplifier, and PD calibrator.

The HV ac supply is a 40 kV, 1.8 kVA transformer whose primary is energized by a 120 V, 22 A motorized variable autotransformer. (Note all voltage and current ratings quoted for the PDA are given in rms units.)

The PSF (Biddle, part no. 8975) is a high voltage capacitor bushing (150 pF, 50 kV) that is interfaced to a series LC network (25 mH and 50 nF). The LC network provides a low level 60 Hz signal for the system HV meter and also couples the high frequency ( $\sim$  MHz) PD signals to the PD amplifier.

The PD amplifier (Biddle, Model 8390) is a vacuum tube circuit that has the very high input impedance ( $\sim 1$  pF/10 M $\Omega$ ) needed to amplify the fast risetime PD pulses. After processing the input PD pulses, the amplifier sends them to the system CRO (Tektronix 556 with type 1A-1 plug-in module) for viewing.

The relationship between the peak voltage output from the PD amplifier and the charge magnitude of the PD signals is determined with a PD calibrator (Biddle, part no. 8975). The input charge magnitude is generally set at 5.0 pC, the standard threshold for identification of the PD inception and extinction voltages, when the calibration is performed. The calibrated sensitivity of the PD detection system was found to be  $< 3$  pC. [3]

#### II.5 High Repetition Rate Pulser

The pulse generator used for high-voltage pulse breakdown experiments is a renovated M.I.T. Model-9 Hard-Tube Pulser. This pulser was originally designed to drive the r.f.-generating magnetron of a radar unit and is described by Glasoe [6]. Several modifications were made to the pulser to permit the present experiments. Most notably, the output pulse duration, which was originally 0.8  $\mu$ s, was made to vary between 0.2 and 6.0  $\mu$ s, depending on the duration of a gating pulse. Also, the risetime of the output pulse, which was nominally 60 ns, can now be increased up to the length of the gating pulse by adjusting an R-C integrator which was installed at the output of the pulser. A block diagram of the system appears in Figure 3.

The high-voltage pulser (HVP) is used to measure the peak value of pulse voltage which can be applied to an insulation specimen and to count the total number of pulses that cause breakdown at a given volt-

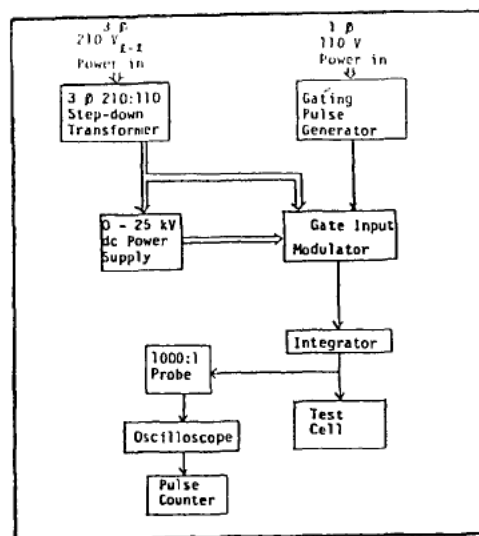


Figure 3. Block diagram of major components of High Voltage Pulser System [4].

age. The HVP permits the HFMR/DDL to conduct unique tests and experiments which explore the influences of pulse risetime, duty cycle and pulsewidth upon the measured values of breakdown voltage for composite insulation systems. These tests are especially significant in the development of high-voltage and pulsed energy source systems because they closely simulate real service conditions. Manipulation of the risetime or pulsewidth allowed three basic types of experiments to be performed. With the pulsewidth held constant, the risetime was varied and the effect on the breakdown characteristics of the test sample was recorded. Also, the risetime was held constant while the pulsewidth was varied and the same type of measurements taken. Finally, the time constant of the RC integrator was increased above the duration of the gating pulse. This produced a ramped voltage, rather than a pulsed voltage, since there was no "flat" portion of the pulse.

#### II.6 Impulse Generation System

The Messwandler-Bau system is a construction-kit which can be rearranged to provide Impulse and Switching Surge voltages up to 200 kV and ac and dc voltages up to 100 kV. In the impulse mode, the system can provide single shot pulses having risetimes varying from 50 ns to 300  $\mu$ s, and a fall time of 1  $\mu$ s to 3000  $\mu$ s. In these experiments, the system is connected to provide an impulse voltage having a 1.5  $\mu$ s risetime and a 50  $\mu$ s fall time. The high voltage is measured by a resistive divider connected to a Tektronix 7623 storage oscilloscope. The storage oscilloscope permitted recording of the peak voltage before breakdown.

#### II.7 Mechanical Test Apparatus

The critical mechanical properties of the insulation samples (i.e., tensile strength, Young's Modulus, complex modulus, and mechanical loss) are examined at the HFMR/DDL both before and after they have been prestressed or electrically tested. The equipment and procedures used in carrying out these mechanical tests are described below.

##### II.7.1 Tensile Strength and Young's Modulus

An Instron Tensile Strength Tester, model 1000, is used to measure the ultimate tensile strength and Young's Modulus for impregnated dielectric film insulation. The sample is gripped and stretched by the machine at a constant rate (e.g., 20 mm/min) and the load is observed on a chart recorder as a function of time. This is equivalent to recording the load as a function of extension since the sample is stretched

at a constant rate. When the specimen fractures, the ultimate tensile strength is determined by dividing the breaking load by the product of film width and thickness.

The Young's Modulus is estimated from the initial part of the load versus time curve as graphed by the chart recorder. The modulus is determined by dividing the measured stress by the measured strain [5].

### II.7.2 Mechanical Loss and Complex Tensile Modulus

The mechanical loss ( $\tan \delta$ ) and complex tensile modulus are measured as a function of temperature using a Rheovibron DDVII dynamic viscoelastometer. As a sinusoidal tensile strain is applied, a stress with a phase-lag is generated and the viscoelastic behavior of the test specimen is characterized by the mechanical  $\tan \delta$ . The frequency of the applied strain can be varied from 3.5 to 110 Hz.

The loss tangent is measured over a specified temperature range (e.g., 20 °C to 110 °C). The dynamic force is also measured as a function of temperature and the absolute value of the complex modulus can be calculated.

### III. Representative Dielectric Analysis

A representative experimental study of the effects of electrical and thermal prestressing on the dielectric and mechanical properties of impregnated polypropylene (PP) films was undertaken at the HFMRL/DDL in order to demonstrate the application of the laboratory facilities to a comprehensive insulation research program. A brief discussion of the relevant experimental conditions is provided below.

#### III.1 Test Conditions

The test specimens consisted of 8  $\mu\text{m}$  thick biaxially oriented PP films (Toray Co., Type 2400) that were cut into rectangular strips (7.0 cm by 37 cm) and impregnated in a commercially available aromatic hydrocarbon oil as described previously. The impregnated samples were then transferred to the aging oven where they were stored between two flat aluminum electrodes in a tray containing the impregnant.

The specimens were then prestressed in the oven under a circulating dry nitrogen atmosphere at a temperature of 70 °C and an ac electric field of 16 V/ $\mu\text{m}$ . The films were aged in the oven for various time periods up to 75 days before electrical and mechanical tests were conducted on them.

#### III.2 Test Results

Representative test results for some of the experiments that can be performed in the HFMRL/DDL are illustrated in Figures 4 to 8. Detailed analysis of the data are not given, as the primary purpose of this paper is to illustrate the experimental capabilities of the facilities.

### IV. Conclusion

The insulation impregnation, prestressing and testing apparatus at the HFMRL/DDL form a comprehensive diagnostic facility that is especially well-suited to the research and development of composite insulation systems proposed for use in HV equipment. As demonstrated by the representative investigation, many important mechanical and electrical properties of the insulation test specimens can be quantitatively evaluated at the HFMRL/DDL under the influence of electrical and thermal prestressing. The information acquired from these tests can lead to a better understanding of the physical processes that govern the dielectric and mechanical characteristics of impregnated insulating films.

The insulation research and development capabilities of the HFMRL/DDL are presently being further advanced via the addition of several more new testing and diagnostic facilities. The new equipment includes a 500 MHz computerized Transient Diagnostic Facility (Tektronix System 62), a 300 kV ac partial discharge

analyzer with 2 pC resolution (Hipotronics, Model 7300-40 CT), a 600 kV, 15 kJ impulse generation system (Hipotronics, Model IG-600-15), a 250 kV fast risetime ( $\sim 1$  ns) pulse-transformer (developed at Sandia), a 300 kV, 2 mA dc supply (Delta Ray, Model L300-2A), a Hamamatsu C-1155 1 ns streak camera (full range to 1 ms), an optical multichannel analyzer (ECG Model 1460 OMA-III), and a Canberra Series 30 multichannel analyzer. These devices can greatly aid in the study of the physical factors responsible for various dielectric phenomena.

Research work presently being performed at the HFMRL/DDL includes:

- o Continued experimental documentation of the influences of electrical and thermal prestressing upon the dielectric properties of polymer film-based insulation systems.
- o Adoption of a transient overvoltage (TOV) test in addition to the PDIV/PDEV measurements. The TOV test is a good measure of the ability of a dielectric specimen to extinguish discharges under practical conditions.
- o Study the effect of the rate of applied voltage rise on the dc, ac, impulse, and pulsed breakdown strength of polymer laminates and relate this information to the operating conditions specified for HV equipment.
- o Determination of the impact of low level ( $< 5$  pC), high frequency, and intermittent PD activity upon the integrity of insulation systems over relatively long time periods through use of the Transient Diagnostic Facility.
- o Conduction of pulse life testing with the HVP by applying repetitive pulses of amplitude  $\sim 60 - 70\%$  of the breakdown level until failure occurs. The number of pulses required for breakdown will be counted and compared to observe any changes in the estimated life with aging.
- o Fast optical diagnostics of pre- and post-breakdown phenomena in gaseous and liquid insulation under the application of repetitive pulsed voltages.
- o Study of the effects of radiation on the physical properties of insulating materials for use in space environments.

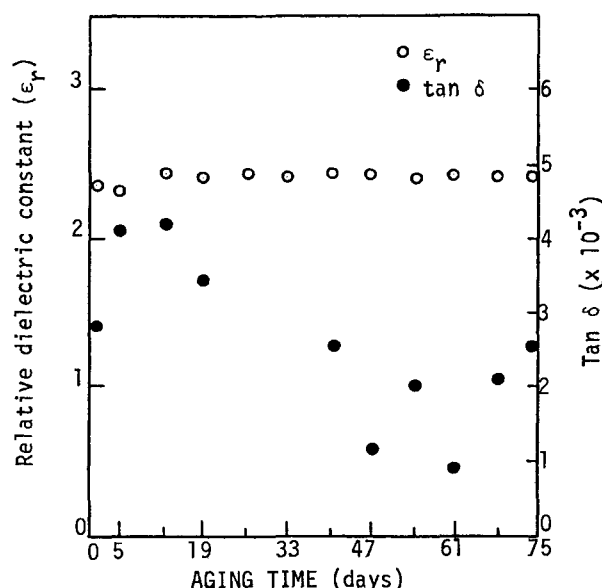


Figure 4. Change in dielectric constant and dielectric loss (at 1 KHz) with aging.[2]

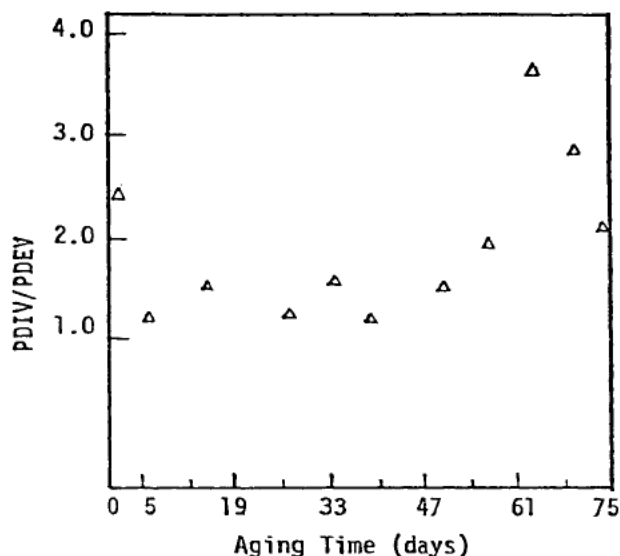


Figure 5. Change in PDIV/PDEV ratio with aging for laminate samples composed of 3 layers of impregnated PP film.

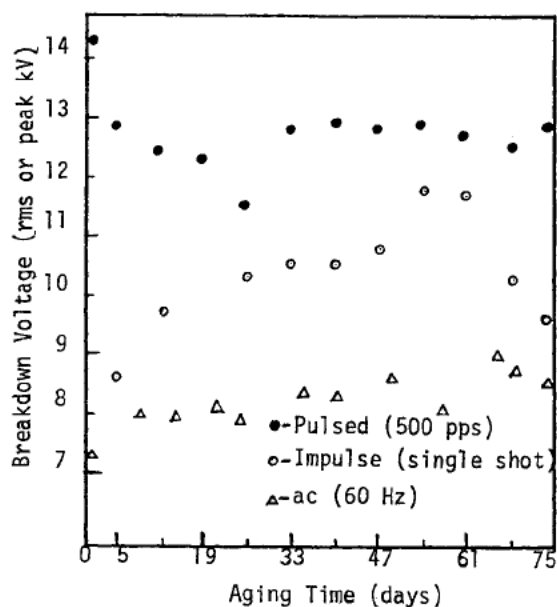


Figure 6. Variation of breakdown voltage with aging for laminate samples composed of 3 layers of PP film.

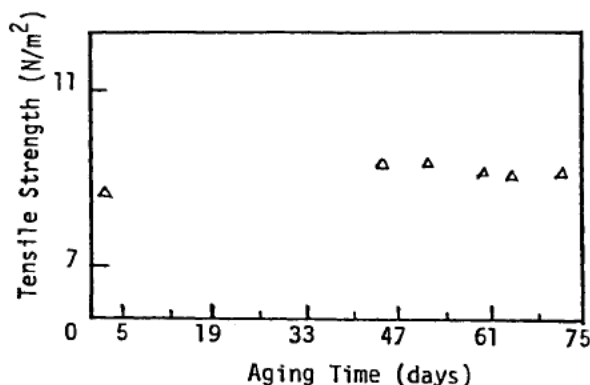


Figure 7. Change in tensile strength with aging. (Data points for the 5 to 33 day period were discarded due to procedural error.) [5]

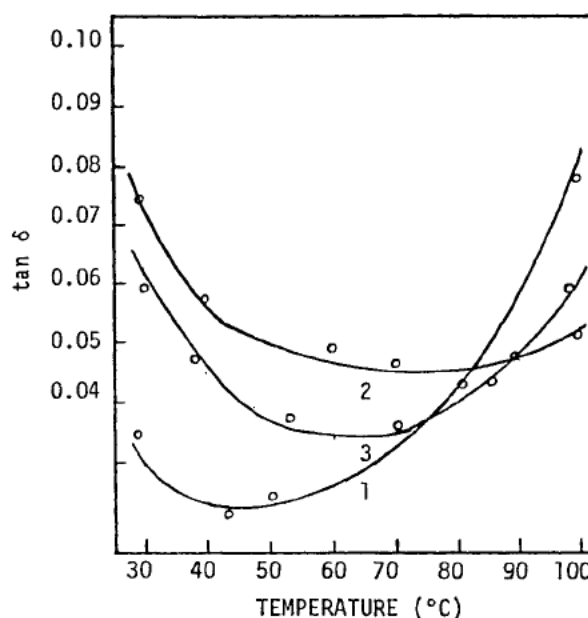


Figure 8. Change in mechanical loss ( $\tan \delta$ ) -temperature dependence with aging (1-unimpregnated, 2-days 0 to 28, 3-days 33 to 75).

#### Acknowledgment

The authors wish to credit the following individuals for their technical assistance and support: Dr. W. J. Sarjeant, Dr. R. E. Dollinger, Dr. E. O. Forster, D. Dettman, M. Nikolich, R. Kraus, J. Shea, M. Belling, M. Rickley, S. Cygan, K. Kumar and J. Bennett.

#### References

1. R. D. McCammon and R. N. Work, "Measurement of the Dielectric Properties and Thermal Expansion of Polymers from Ambient to Liquid Helium Temperatures," *The Review of Scientific Instruments*, Vol. 36, No. 8, August 1965, pp. 1169-1174.
2. A. N. Hammoud, "Partial Discharge Induced Breakdown of Laminate Insulation Structures," Masters Thesis, SUNY at Buffalo, September 1984.
3. T. M. Bilodeau, "Design and Development of an ac Partial Discharge Detection System," Masters Thesis, SUNY at Buffalo, February 1985.
4. M. P. Treanor, "The Effect of Pulse Shape on the Electrical Breakdown of Some Polymers," Masters Thesis, SUNY at Buffalo, December 1984.
5. J. R. Laghari, W. J. Sarjeant and R. K. Gupta, *A Comparison of Four Liquid Impregnants for Use in Power Capacitors*, Final Report to Exxon Chemical Company, SUNY at Buffalo, December 1984.
6. G. N. Glasoe and J. V. Lebacqz, ed.s, *Pulse Generators*, Dover Publications, Inc., NY, 1965.